5.2 RF AMPLIFIERS:

CHARACTERISTICS OF AMPLIFIERS:

The most important and complex task is the amplification of an input signal through either a single or multistage transistor circuit. A generic single-stage amplifier configuration embedded between input and output matching networks, as shown in Fig 5.2.1.

Input and Output matching networks, are needed to reduce undesired reflections and thus improve the power flow capabilities. Interms of performance specifications, the following list constitutes a set of key amplifier parameters.

- Gain and gain flatness
- Operating frequency and bandwidth
- Output power
- Power supply requirements
- Input and output power reflections
- Noise figure Γ_S

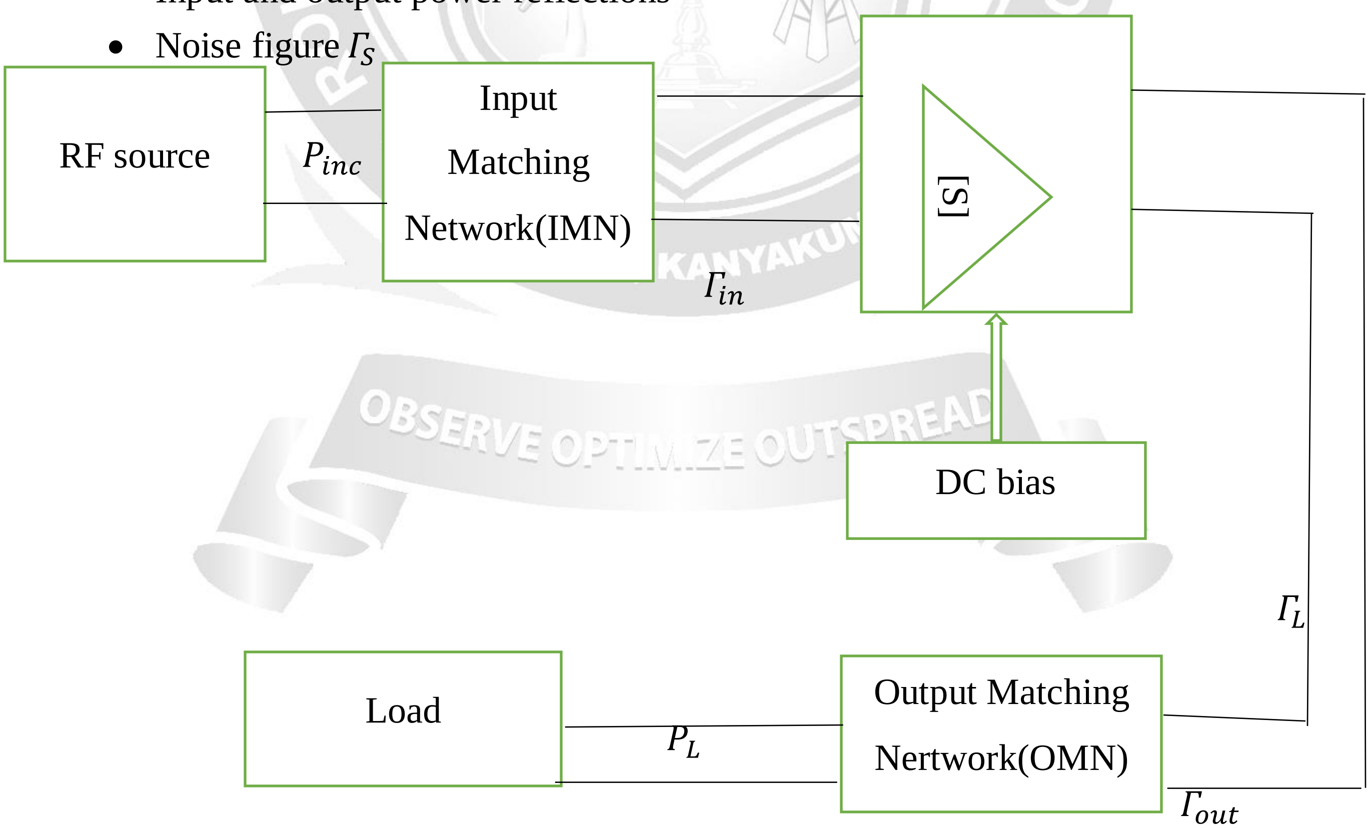

Fig: 5.2.1 Generic amplifier system

i. Reflection Coefficient seen looking toward the load

$$\Gamma_L = \frac{Z_L - Z_O}{Z_L + Z_O}$$

ii. Reflection Coefficient seen looking toward the source

$$\Gamma_S = \frac{Z_S - Z_O}{Z_S + Z_O}$$

iii. Input reflection Coefficient

$$\Gamma_{in} = S_{11} + \frac{S_{12}\, S_{21}\, \Gamma_L}{1 - S_{22}\, \Gamma_L}$$

iv. Output reflection Coefficient

$$\Gamma_{out} = S_{22} + \frac{S_{12}\, S_{21}\, \Gamma_S}{1 - S_{11}\, \Gamma_s}$$

From signal flow graph In figure,

$$b_s + a_1'\Gamma_S = b_1'$$

$$b_s = b_1' - a_1'\Gamma_S$$

$$b_s = b_1'\left[1 - \frac{a_1'}{b_1'}\,\Gamma_S\right]$$

$$b_s = b_1'\left[1 - \frac{b_1}{a_1}\,\Gamma_S\right]$$

$$b_s = b_1'\,[1 - \Gamma_{in}\,\Gamma_S] \qquad \text{.........(1)}$$

$$b_1' = \frac{b_s}{1 - \Gamma_{in}\,\Gamma_S} \qquad \text{......(2)}$$

Incident power wave (P_{inc}) associated with b_1' is given as,

$$P_{inc} = \frac{|b_1'|^2}{2}$$

$$P_{inc} = \frac{1}{2}\,\frac{|b_s|^2}{|1 - \Gamma_{in}\,\Gamma_S|^2} \qquad \text{......(3)}$$

which is the power launched towards the amplifier,

$$\Gamma_{in} = 0 \;\&\; \Gamma_S \neq 0$$

$$P_{inc} = \frac{|b_s|^2}{2} \qquad \text{.......(4)}$$

The actual input power P_{in} is observed at the input terminal of the amplifier is composed of the incident & reflected power waves.

$P_{in} = P_{inc}\ (1 - |\Gamma_{in}|^2)$

$P_{in} = \frac{1}{2}\frac{|b_s|^2}{|1 - \Gamma_{in}\,\Gamma_S|^2}\,(1 - |\Gamma_{in}|^2)$ …..(5)

Maximum power transfer from the source to the amplifier is achieved if the input impedance is complex conjugate matched ($Z_{in} = Z_v$) or, in terms of the reflection coefficients if $\Gamma_{in} = \Gamma_S{}^*$

Under maximum power transfer condition, the available power P_A as,

$$P_A = P_{in}|_{\Gamma_{in} = \Gamma_S{}^*}$$

$$P_A = \frac{1}{2}\frac{|b_s|^2}{|1 - \Gamma_{in}\,\Gamma_S|^2}\,(1 - |\Gamma_{in}|^2)\Big|_{\Gamma_{in} = \Gamma_S{}^*}$$

$$P_A = \frac{1}{2}\frac{|b_s|^2}{|1 - |\Gamma_S|^2|^2}\,(1 - |\Gamma_s|^2)$$

$$P_A = \frac{1}{2}\frac{|b_s|^2}{(1 - |\Gamma_s|^2)} \qquad \text{……(6)}$$

Power delivered to the load is given by,

$$P_L = \frac{1}{2}\,|b_2|^2\ (1 - |\Gamma_L|^2) \qquad \text{……(7)}$$

<u>TRANDUCER POWER GAIN</u>

$$G_T = \frac{power\ delivered\ to\ the\ load}{available\ power\ from\ the\ source} \qquad \text{….. (1)}$$

$$G_T = \frac{P_L}{P_{av(s)}} = \frac{P_L}{P_A} \qquad \text{…… (2)}$$

$$P_L = \frac{1}{2}\,|b_2|^2\ (1 - |\Gamma_L|^2) \qquad \text{……(3)}$$

$$P_A = \frac{|b_s|^2}{(1 - |\Gamma_s|^2)} \qquad \text{…..(4)}$$

Sub equ (3) and (4) in equ (2),

$$G_T = \frac{\frac{1}{2}|b_2|^2\ (1 - |\Gamma_L|^2)}{\frac{|b_S|^2}{(1 - |\Gamma_S|^2)}}$$

$G_T = \left|\frac{b_2}{b_s}\right|^2 (1\text{-}\ |\Gamma_L|^2)\ (1 - \ |\Gamma_s|^2)$ ……(5)

The reflected wave at port 2 is b_2,

$b_2 = \frac{a_1 S_{21}}{1-S_{22}\Gamma_L}$ …….(6)

By rearranging the above equation (6),

$b_2(1 - S_{22}\,\Gamma_L) = a_1 S_{21}$

$a_1 = \frac{b_2(1-S_{22}\Gamma_L)}{S_{21}}$ …….(7)

The source reflection coefficient b_s is given by,

$b_s = (1 - \Gamma_S \Gamma_{in})\ a_1$ ……(8)

The input reflection coefficient Γ_{in} is given by,

$\Gamma_{in} = S_{11} + \frac{S_{12}\,S_{21}\,\Gamma_L}{1-\,S_{22}\,\Gamma_L}$ …….(9)

By rearranging the equ (11) by,

$\Gamma_{in} = \frac{S_{11}\,(1-\,S_{22}\,\Gamma_L) + S_{12}\,S_{21}\,\Gamma_L}{1-\,S_{22}\,\Gamma_L}$

<u>To find 1- $\Gamma_S \Gamma_{in}$:</u>

$\Gamma_S \Gamma_{in} = \frac{S_{11}\,(1-\,S_{22}\,\Gamma_L)\Gamma_S + S_{12}\,S_{21}\,\Gamma_L\,\Gamma_S}{1-\,S_{22}\,\Gamma_L}$

$1\text{-}\ \Gamma_S \Gamma_{in} = 1\text{-}\ \frac{S_{11}\,(1-\,S_{22}\,\Gamma_L)\Gamma_S + S_{12}\,S_{21}\,\Gamma_L\,\Gamma_S}{1-\,S_{22}\,\Gamma_L}$

$= 1\text{-}\ \frac{S_{11}\,\Gamma_S - S_{11}\,S_{22}\,\Gamma_L\,\Gamma_S + S_{12}\,S_{21}\,\Gamma_L\,\Gamma_S}{1-\,S_{22}\,\Gamma_L}$

$= \frac{(1-\,S_{22}\,\Gamma_L) - \,S_{11}\,\Gamma_S - S_{11}\,S_{22}\,\Gamma_L\,\Gamma_S - \,S_{12}\,S_{21}\,\Gamma_L\,\Gamma_S}{1-\,S_{22}\,\Gamma_L}$

$= \frac{(1-\,S_{22}\,\Gamma_L) - \,S_{11}\,\Gamma_S(1-S_{22}\,\Gamma_L) - \,S_{12}\,S_{21}\,\Gamma_L\,\Gamma_S}{1-\,S_{22}\,\Gamma_L}$

$= \frac{(1-\,S_{22}\,\Gamma_L)(1-\,S_{11}\,\Gamma_S) - \,S_{12}\,S_{21}\,\Gamma_L\,\Gamma_S}{1-\,S_{22}\,\Gamma_L}$ ….(12)

To find b_s:

Sub equ (12) in equ (8),

From equ (8),

$b_s = (1 - \Gamma_S \Gamma_{in})\, a_1$

$$b_s = \left[\frac{(1- S_{22}\,\Gamma_L)(1- S_{11}\,\Gamma_S) - S_{12}\, S_{21}\,\Gamma_L\,\Gamma_S}{1- S_{22}\,\Gamma_L}\right] a_1 \quad \text{.....(13)}$$

Sub equ (7) in equ (13),

$$b_s = \left[\frac{(1- S_{22}\,\Gamma_L)(1- S_{11}\,\Gamma_S) - S_{12}\, S_{21}\,\Gamma_L\,\Gamma_S}{1- S_{22}\,\Gamma_L}\right] \text{x}\ \frac{b_2(1-S_{22}\Gamma_L)}{S_{21}}$$

$$\frac{b_s}{b_2} = \frac{(1- S_{22}\,\Gamma_L)(1- S_{11}\,\Gamma_S) - S_{12}\, S_{21}\,\Gamma_L\,\Gamma_S}{S_{21}} \quad \text{.....(14)}$$

To find $\left|\frac{b_s}{b_2}\right|^2$:

$$\left|\frac{b_s}{b_2}\right|^2 = \frac{|S_{21}|^2}{\left|(1- S_{22}\,\Gamma_L)(1- S_{11}\,\Gamma_S) - S_{12}\, S_{21}\,\Gamma_L\,\Gamma_S\right|^2} \quad \text{.....(15)}$$

To find G_T,

From equ (5),

$$G_T = \left|\frac{b_2}{b_s}\right|^2 (1 - |\Gamma_L|^2)\,(1 - |\Gamma_s|^2)$$

$$G_T = \frac{|S_{21}|^2\,(1- |\Gamma_L|^2)\,(1- |\Gamma_s|^2)}{\left|(1- S_{22}\,\Gamma_L)(1- S_{11}\,\Gamma_S) - S_{12}\, S_{21}\,\Gamma_L\,\Gamma_S\right|^2}$$

$$G_T = \frac{|S_{21}|^2\,(1- |\Gamma_L|^2)\,(1- |\Gamma_s|^2)}{|1- S_{22}\,\Gamma_L|^2\,|1-\Gamma_S\Gamma_{in}|^2}$$

Problem 1:

An amplifier has the following S-parameters : S_{11}=0.3∟-70, S_{12}=0.2∟-10, S_{21}=3.5∟85 and S_{22}=0.4∟-45. Furthermore, input side of the amplifier is connected to a voltage source with V_S = 5V∟0 and the source impedance Z_S = 40ohm. The output is utilized to drive the antenna which has an impedance of Z_L = 73ohm. Assuming that the S-parameters of the amplifier are measured with reference to a Z_O = 50ohm characteristic impedance, Calculate

a) transducer gain, unilateral transducer gain, available gain, operating power gain.

b) Power delivered to the load , available power and incident power to the amplifier.

Given data:

S_{11}=0.3∟-70

S_{12}=0.2∟-10

S_{21}=3.5∟85

S_{22}=0.4∟-45

Z_S = 40ohm

Z_L = 73ohm

Z_O = 50ohm

V_S = 5V∟0

$\boldsymbol{\Gamma_L} = \frac{Z_L - Z_O}{Z_L + Z_O}$

$\Gamma_L = \frac{73-50}{73+50}$

$\boldsymbol{\Gamma_L}$ **= 0.187**

$\boldsymbol{\Gamma_S} = \frac{Z_S - Z_O}{Z_S + Z_O}$

$\Gamma_S = \frac{40-50}{40+50}$

$\boldsymbol{\Gamma_S}$ **= -0.111**

$\boldsymbol{b_s} = \frac{\sqrt{Z_O}}{Z_S + Z_O} V_S$

$b_s = \frac{\sqrt{50}}{40+50} 5$

$\boldsymbol{b_s}$ **= 0.392**

$\boldsymbol{\Gamma_{in}} = S_{11} + \frac{S_{12} S_{21} \Gamma_L}{1 - S_{22} \Gamma_L}$

Γ_{in} = 0.3∟-70 + $\frac{(0.2∟-10)(3.5∟85\,)\,(0.187)}{1-(0.4∟-45)(0.187)}$

Γ_{in} = 0.3∟-70 + $\frac{(0.7∟75)\,(0.187)}{1-(0.0748\,∟-45)}$

Γ_{in} = 0.3∟-70 + $\frac{(0.1309\,∟75)}{1-(0.0748\,∟-45)}$

Γ_{in} = 0.3∟-70 + 0.138 ∟71.81

Γ_{in} = 0.209∟-45.98

$\Gamma_{out} = S_{22} + \frac{S_{12}\,S_{21}\,\Gamma_S}{1-S_{11}\,\Gamma_s}$

Γ_{out} = 0.4∟-45 + $\frac{(0.2∟-10)(3.5∟85\,)\,(-0.111)}{1-(0.3∟-70)(-0.111)}$

Γ_{out} = 0.4∟-45 + $\frac{(0.7∟75)\,(-0.111)}{1-0.333∟-70}$

Γ_{out} = 0.4∟-45 + $\frac{(0.0777∟75)}{1-0.333∟-70}$

Γ_{out} = 0.4∟-45 + 0.0767∟76.77

Γ_{out} = 0.445∟-53.42

a) Transducer gain, unilateral transducer gain, available gain, operating power gain.

$G_T = \frac{|S_{21}|^2\,(1-|\Gamma_L|^2)\,(1-|\Gamma_s|^2)}{|1-S_{11}\,\Gamma_S|^2\,|1-\Gamma_{out}\Gamma_L|^2}$

$G_T = \frac{(3.5)^2\,(1-(0.187)^2)\,(1-(-0.111)^2)}{|1-(0.187)(0.445∟-53.42)|^2\,|1-(0.3∟-70)(-0.111)|^2}$

G_T = 12.556

G_T(dB) = 10 log_{10} (G_T)

G_T(dB) = 10 log_{10} (12.556)

G_T(dB) = 10.988 dB

$G_{TU} = \frac{|S_{21}|^2\,(1-|\Gamma_L|^2)\,(1-|\Gamma_s|^2)}{|1-S_{22}\,\Gamma_L|^2\,|1-S_{11}\,\Gamma_S|^2}$

G_{TU} = 12.68

G_{TU}(dB) = 10 log_{10} (G_{TU})

G_{TU}(dB) = 10 log_{10} (12.68)

G_{TU}(dB) = 11.03 Db

$$G_A = \frac{|S_{21}|^2 (1-|\Gamma_s|^2)}{|1-S_{11}\Gamma_S|^2 (1-|\Gamma_{out}|^2)}$$

G_A = 14.74

G_A(dB) = 10 log_{10} (G_A)

G_A(dB) = 10 log_{10} (14.74)

G_A(dB) = 11.68 dB

$$G = \frac{|S_{21}|^2 (1-|\Gamma_L|^2)}{(1-|\Gamma_{in}|^2)|1-S_{22}\Gamma_L|^2}$$

G = 13.75

G(dB) = 10 log_{10} (G)

G(dB) = 10 log_{10} (13.75)

G(dB) = 11.38 dB

b) Power delivered to the load , available power and incident power to the amplifier.

$$P_{inc} = \frac{1}{2}\frac{|b_s|^2}{|1-\Gamma_{in}\Gamma_S|^2}$$

P_{inc} = 0.0733W

$$P_{inc}\,(\text{dBm}) = 10\ log_{10}\left(\frac{P_{inc}\,(\text{watts})}{1mW}\right)$$

$$P_{inc}\,(\text{dBm}) = 10\ log_{10}\left(\frac{0.0733}{1\ X\ 10^{-3}}\right)$$

P_{inc} (dBm) = 18.65 dBm

$$P_A = \frac{1}{2}\frac{|b_s|^2}{(1-|\Gamma_s|^2)}$$

$$P_A = \frac{1}{2}\frac{(0.392)^2}{(1-(-0.111)^2)}$$

P_A = 0.0778 W

P_A **(dBm) = 10** $log_{10}\left(\frac{P_A\,(\text{watts})}{1mW}\right)$

P_A **(dBm) = 18.909 dBm**

$G_T = \frac{P_L}{P_A}$

$P_L = P_A\ G_T$

P_L **= 0.976 W**

P_L **(dBm) = 10** $log_{10}\left(\frac{P_L\,(\text{watts})}{1mW}\right)$

P_L **(dBm) = 29.89 dBm**